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Simulating the Climatic Effects of Potentially Hazardous Asteroids Using a Chemistry-Climate Model

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Introduction

Asteroid impacts have the potential to significantly perturb Earth's climate system. Depending on the scenario (size, composition, impacting surface) the impact could result in atmospheric injections of water, dust, soot from fires, and other important trace constituents. Using the Goddard Earth Observing System Chemistry-Climate Model (GEOSCCM) coupled to a dynamical ocean, chemistry, and aerosol modules, the extent of the climate effect can begin to be assessed. Here, we examine an initial example in modeling the 2015 Planetary Defense Conference (PDC) tabletop exercise, focusing on important regional and global climatic quantities. In this exercise an approximately 80 m asteroid causes an ~18-25 Mt air burst over Dhaka, Bangladesh. The resulting fires would emit a significant amount of soot into the atmosphere, which strongly absorbs shortwave radiation, impacting Earth's climate. Here, we present the initial results of this scenario on climate.

Model Description and Scenario

We used the Goddard Earth Observing System Chemistry-Climate Model (GEOSCCM) with a coupled dynamical ocean to simulate the spread and effect of soot aerosol from fires generated as a result of PDC tabletop exercise scenario.

The model was run at 2° x 2.5° horizontal resolution with 72 vertical layers in the atmosphere and approximately 1° horizontal resolution in the ocean and 50 vertical layers.

This simulation was forced with observed natural and anthropogenic emission sources for present day.

The soot was injected into the 3 vertical layers between 16.5 and 19 km over Dhaka, Bangladesh (23.6°N, 90.3°E) on Sept. 3, 2022.

Damage maps for final footprint

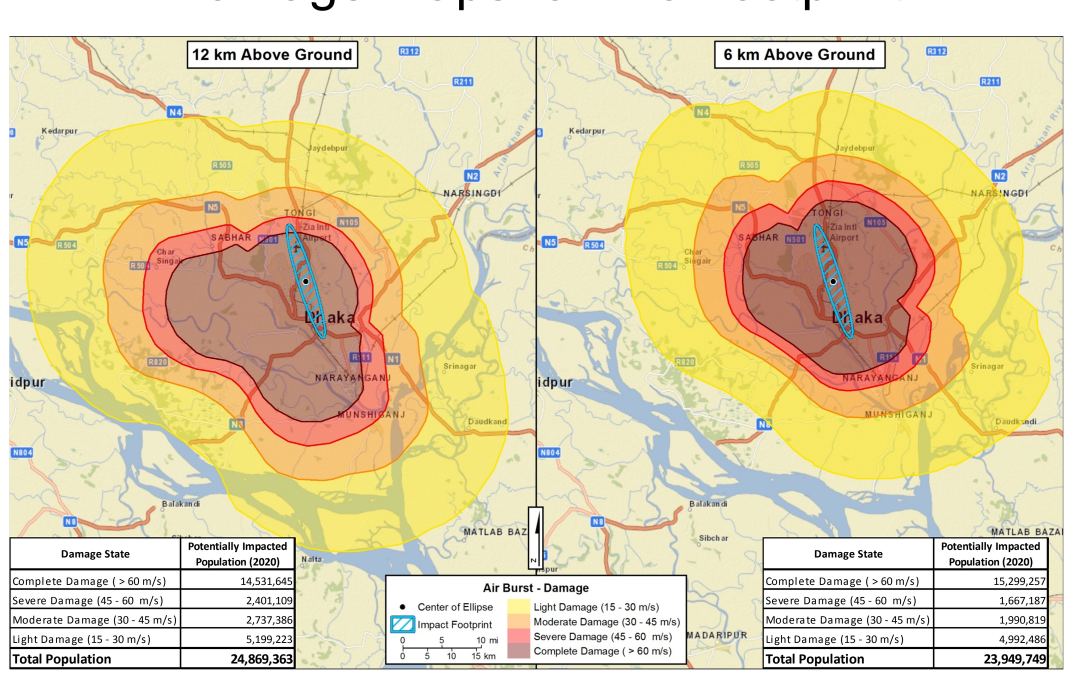


Figure courtesy of Mark Boslough, Barbara Jennings, and Bill Fogelman

We used the area of complete damage and population impacted to calculate the soot emissions from fires using Toon et al. (2007).

Assumptions: ~ 15 million people (P) in complete damage area, fires ignite over half that area impacting ~7.5 million people

Fuel mass per person $M_f = 1.1 \times 10^7$ g/person

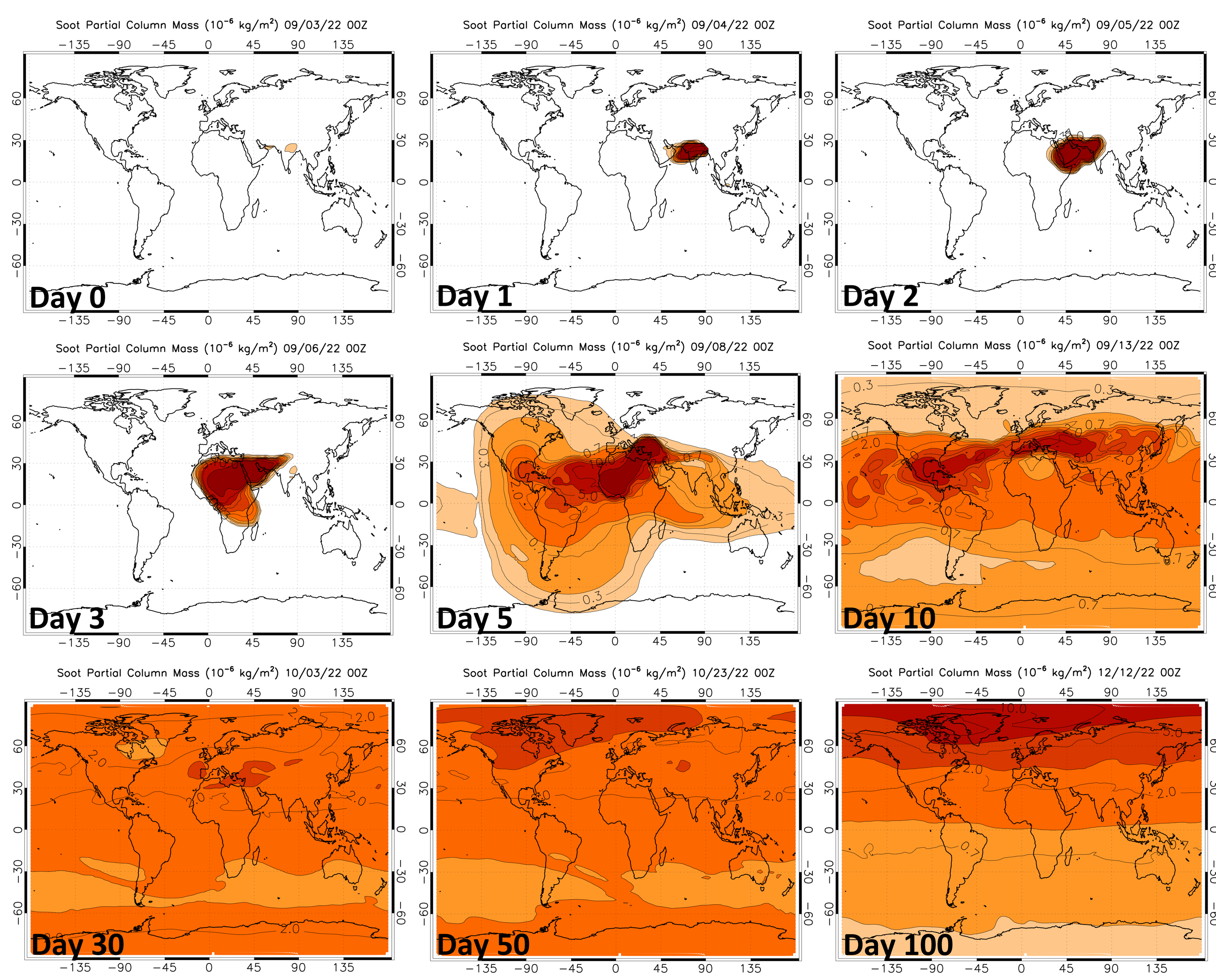
Fuel consumed by fires $F_m = M_f * P = 8.25 \times 10^{13}$ g = 82.5 Tg

Soot mass produced S_m = 82.5 Tg * 0.02 g of soot/g of fuel =1.65 Tg soot

Additional factors 0.5x for developing world and 1.2x increase use of plastics from 1980-2020s:

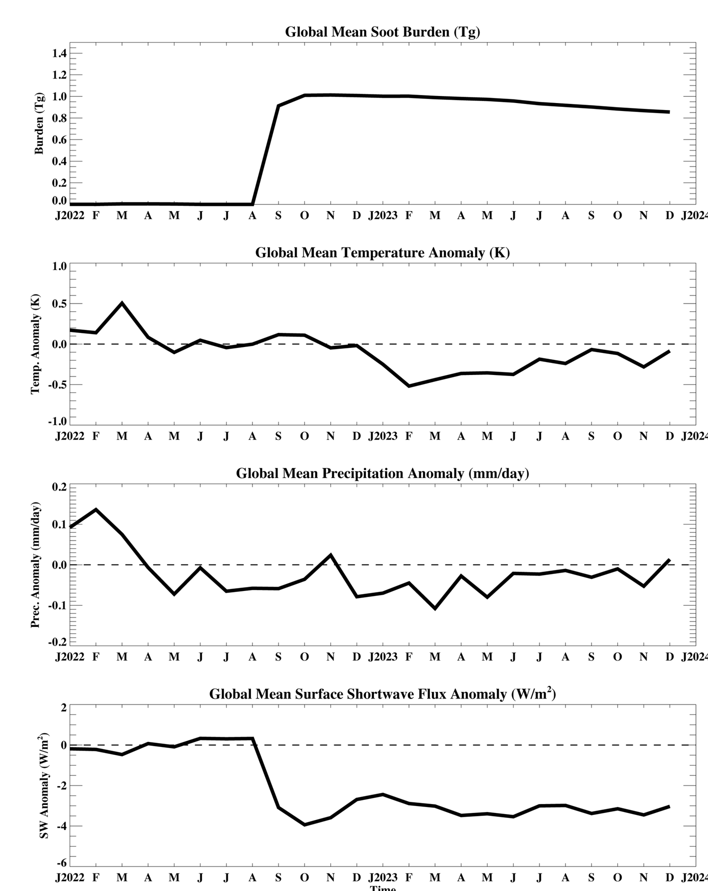
Yields ~ 1 Tg of Soot emitted

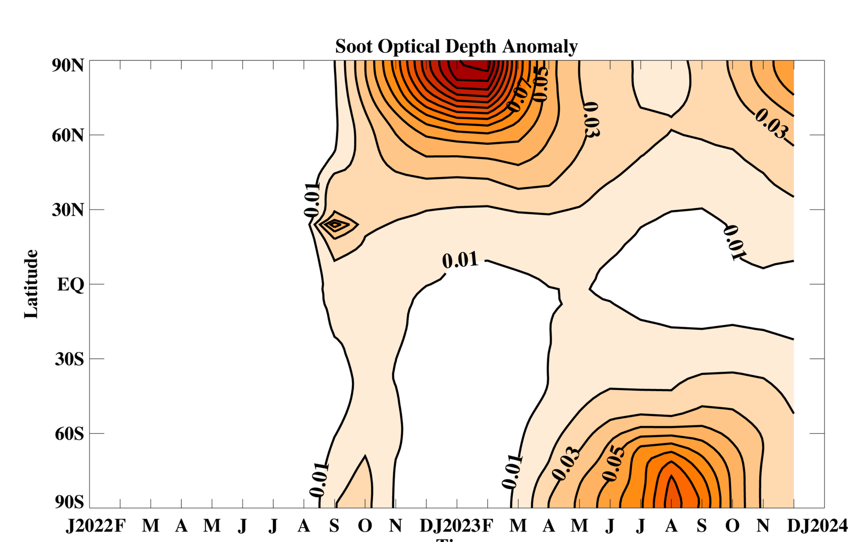
Initial Spread of Fire Generated Soot

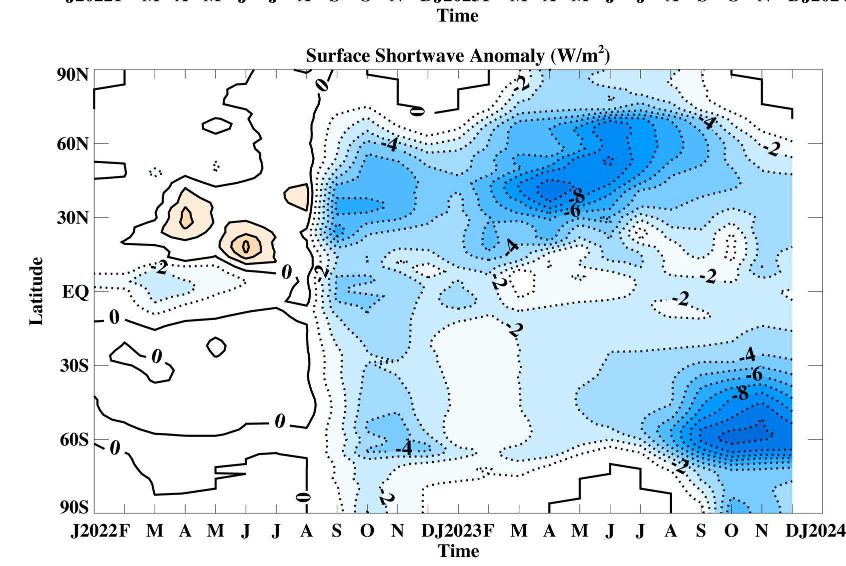


Global Climate Impacts

Once the soot reaches high in the stratosphere, removal mechanisms are slow and are largely governed by the overturning circulation. This causes the soot aerosol to remain in the atmosphere for many years. The global temperature decreases 0.3-0.5 K and precipitation generally decreases 0.05-0.1 mm/day. The soot is highly absorbing over the visible wavelengths and results in a ~-4 W/m² anomaly at the surface.



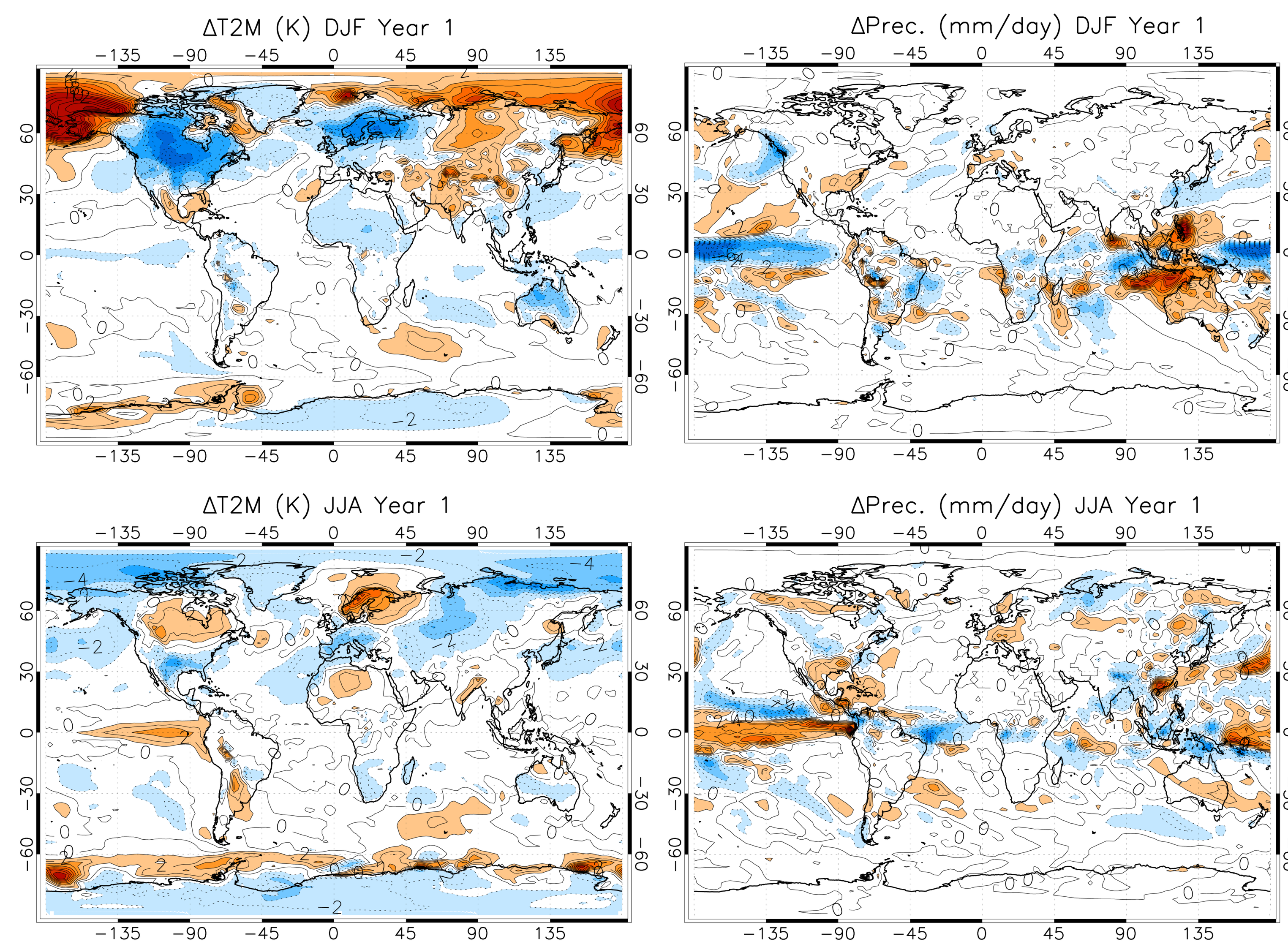




Approximately 2/3 of the soot optical depth is from absorption with the remaining 1/3 due to back-scattering. This is in contrast to sulfate aerosols which are largely scattering. The circulation in the upper stratosphere and meso-sphere transports the soot aerosols toward the winter hemisphere. The surface shortwave (SW) anomaly maximizes in the mid-latitudes in the respective spring/summer seasons.

Regional Climate Impacts

The regional surface temperature changes, especially due to dynamical changes, can be quite large. While the decreased SW radiation reaching the surface causes a smaller overall cooling, the weakened polar vortex causes stronger local cooling over North America and Europe during DJF and warming over the Southern Ocean during JJA, which is due to weaker upwelling and mixing.



Where we need improved understanding

- Improved estimates of fire initiation area
- Better constraints on soot particle size and optical properties
- Injection amounts and height

Conclusions

A first estimate of the soot produced from fires initiated by the PDC exercise scenario asteroid was calculated. Approximately 1 Tg of soot was injected just above the tropopause and interactively transported, the heating of the soot causes it to rise high in the stratosphere and spread globally. The global surface shortwave anomaly approaches -4 W/m² which is similar to that produced by the Mt. Pinatubo eruption due to a much higher loading of sulfate aerosols. The global temperature and precipitation anomalies are as expected from the radiative anomaly and compared to previous soot impact work (Robock et al., 2007). Much larger regional anomalies can result, however more simulations will be necessary to assess statistical significance.

Acknowledgements

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References

Toon, O. B., R. P. Turco, A. Robock, C. Bardeen, L. Oman, and G. L. Stenchikov, 2007: Atmospheric effects and societal consequences of regional scale nuclear conflicts and acts of individual nuclear terrorism. *Atm. Chem. Phys.*, 7, 1973-2002.

Robock, A., L. Oman, G. L. Stenchikov, O. B. Toon, C. Bardeen, and R. P. Turco, 2007: Climatic consequences of regional nuclear conflicts. *Atm. Chem. Phys.*, 7, 2003-2012.